The Analysis, Numerical Simulation, and Diagnosis of Extratropical Weather Systems

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LONG-TERM GOAL

My long-term goal is to contribute to the advancement of the observation, structural analysis, dynamical diagnosis and numerical prediction of the life cycles of planetary-scale, synoptic-scale and mesoscale weather systems, including the influence of inter-annual and intra-seasonal climate variability on their evolution. These weather systems include: oceanic and land-falling cyclones, fronts and their associated cloud, wind, and precipitation systems; upper-level jet streams and clear-air turbulence, extreme orographic flows and their interactions with the ocean.

OBJECTIVES

My research over the past year has focused on the following objectives: i) the planning of the U.S. Weather Research Program (USWRP) research initiative for the development of next-generation operational observing systems and their assimilation for improved 2-10 day weather forecasts, ii) the synoptic analysis and four-dimensional data assimilation of observations taken during the Fronts and Atlantic Storm-Track Experiment (FASTEX, 1997), North Pacific Experiment (NORPEX, 1998), and Winter Storm Reconnaissance Program (WSRP 1999), iii) the diagnosis and dynamical interpretation of research and operational targeted observations over the North Pacific Ocean, and the impact of these observations on the 2-10 day prediction of high-impact weather events, iv) the numerical simulation and observational validation of high-resolution (~10 km) numerical forecasts of oceanic boundary-layer jet streams and extratropical coastal cyclones, v) research aircraft observations and numerical simulations of gravity-waves and associated jet-stream turbulence, vi) the development of the Driftsonde balloon-born dropsonde wind, temperature, and humidity profiling system, and vii) the use of the NOAA/G-4 aircraft dropsonde profiles for the calibration/validation of polar and geostationary satellite atmospheric and ocean-surface remote sensing observations.

APPROACH

My approach has been to foster interactions between US and International Agencies, and talented scientists to develop the research teams required to address the above complex objectives. The support that I have received through this ONR-sponsored grant (N0001499F0068) has been applied to my NOAA salary for ONR related research, visits with ONR collaborators, publication costs, attendance of USWRP meetings and science symposia, and research presentations at national and international symposia, universities, and workshops. The following identifies selected tasks and the individuals that I collaborated with in order to achieve the above objectives:

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14. ABSTRACT
My long-term goal is to contribute to the advancement of the observation, structural analysis dynamical diagnosis and numerical prediction of the life cycles of planetary-scale, synoptic-scale and mesoscale weather systems, including the influence of inter-annual and intra-seasonal climate variability on their evolution. These weather systems include: oceanic and land-falling cyclones, fronts and their associated cloud, wind, and precipitation systems; upper-level jet streams and clear-air turbulence, extreme orographic flows and their interactions with the ocean.

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The sensitivity of medium-range ensemble weather forecasts to differing time-mean flow regimes: This effort is a new collaboration with Isla Gilmour (NCAR/ASP) and David Baumheffner (NCAR/Climate Division). The work was motivated, in part, by the findings showing the influence of the differing phases of ENSO on the 3-day performance of NRL/NOGAPS forecasts (See Shapiro, et al 2000). See **Fig. 1** at end of this report for an example of differences in Rossby wave breaking between El Niño and La Niña. For the present effort, ensemble forecasting methods are used to study forecast model predictability sensitivity to differing time-mean flows, such as strong zonal flow across the North Pacific Ocean, large amplitude "blocking" patterns, and variations in meridional barotropic shear. We are also investigating the possible influence of differing time-mean flows on the predictability of baroclinic and barotropic Rossby-wave energy dispersion (downstream development).

The northern Hemispheric Observing-system Research and Predictability EXperiment (THOR*PEX*): I participated in the preparation of the preliminary Science Plan for The northern-Hemispheric Observing-system Research and Predictability Experiment; in collaboration with Rolf Langland (NRL/Monterey) and Andrew Lorenc (UK Meteteorological Service*).* My effort contributed to THOR*PEX* becoming a priority initiative of the US Weather Research. THOR*PEX* has broadened into an international collaboration between the United States, European Community, Russia, Japan and China. The primary objective of this program is to improve short-range (2–3 day) and extended-range (4-10 day) forecasts of high-impact weather. The THOR*PEX* Science Plan is posted at http://box.mmm.ucar.edu/uswrp/ under USWRP Programs/Field Projects. See **Fig. 2** at end of this report for an example of forecast sensitivity to initial observations over the mid-Pacific Ocean

Synoptic analysis and data assimilation studies: I prepared synoptic analysis of dropdsonde observations of oceanic cyclones with Nick Bond (NOAA/PMEL). These analyses are used to evaluate the realism of mesoscale numerical simulations with the NRL/Coupled Ocean Atmospheric Prediction System(COAMPS) and the Penn. State/NCAR prediction system(MM-5) by Jim Doyle and William Thompson (NRL/Monterey), and Nelson Seaman (Penn. State Univ.), respectively. In addition, these analyses were assimilated into the 4D-Var data assimilation system by Xiaolei Zou (Fla. St. Univ).

The development of the Driftsonde balloon-born dropsonde system: I worked with Hal Cole (NCAR/ATD) and Rolf Langland (NRL/MRY) in the design of a revolutionary ballon-born GPS dropsonde system for obtaining low-cost *in situ* profiles of wind, temperature and humidity over the data-sparse expanses of the oceans. It is anticipated that Driftsonde will provide high-quality upper-air data in THOR*PEX* and for enhancing observations over the tropical Atlantic and Pacific oceans during future field studies of the USWRP Hurricanes at Landfall research initiative. Driftsonde has the potential to become an operational component of the global observing upper-air network.

SSMIS-Callibration/Validation through high-spatial resolution NOAA/G-4 aircraft dropsondes : Rolf Langland (NRL/MRY) and I developed a collaboration with the NRL/SSMIS Lower-Atmospheric Sounding Capability program; Gene Poe (NRL, Team Leader). The effort is being coordinated with Steve Swadley (NRL/MRY) as a collaboration between NRL/MRY, the NOAA/NCEP Winter Storm Reconnaissance Program (WSRP), and NOAA/ETL. During February 2001, high-spatial resolution (~40 km) dropsondes will be deployed from the NOAA/G-4 during flights from Hawaii to validate SSMIS thermodynamic retrievals.

WORK COMPLETED

Preparation of the THOR*PEX* proposal presented to the WMO/WWRP in September 2000; in collaboration with Rolf Langland (NRL/MRY) and Andrew Lorenc (UK Met. Service).

Published the results of adaptive observing strategies from the FASTEX targeted observing studies (Langland et al 1999).

The structure and numerical simulation of low-level oceanic jet streams and their interaction with the ocean surface from FASTEX and NORPEX; in collaboration with William Thompson (NRL./Monterey) and Nick Bond (NOAA/PMEL); two conference preprints.

The influence of time-variant mean flows over the North Pacific on extratropical baroclinic life cycles during ENSO; in collaboration with Heini Wernli (Univ. Zurich CH), Nick Bond (PMEL/Univ. Washington) and Rolf Langland(NRL/MRY); *Q. J. Roy. Met. Soc.* (accepted for publication).

Four-dimensional data assimilation of targeted dropwindsondes, and satellite observations of total columnar ozone and cloud- and water-vapor drift winds in collaboration with Xiaolei Zou (Fla. State. Univ.), Chris Velden (Univ. Wisc.), and Arlin Krueger (NASA/GSFC); one journal paper submitted

RESULTS

Our ONR supported research on the effects of the El Niño Southern Oscillation (ENSO) on extratropical baroclinic life cycles (Shapiro, et al. 2000) has suggested that different time-mean flows between the El Niño and La Niña regimes give rise to significantly different extratropical cyclone life cycles. Results also suggest that differing inter-annual and intra-seasonal time-mean flows impact upon the accuracy of numerical forecasts. These results have been presented at the European Geophysical Society Annual Meeting (Nice, Fance; April 2000), the Extratropical Cyclone Workshop (Monterey, CA; Sept. 2000), and in seminars at NCAR, NOAA, and at US and international universities. The results (Shapiro, et al. 2000) have been accepted for publication in the *Quart. J. Roy. Meteor., Soc.*.

IMPACT/APPLICATION

The above described work is at the frontiers of meteorological research and operational forecasting. We have made contributions on problems in the areas of: i) inter-annual climate variability impacts on extratropical cyclones, ii) targeted observing strategies, iii) four-dimensional data assimilation, iv) *in situ* observing systems (Driftsonde), and v) the organization of The Hemispheric Observing-system and Predictability Experiment (THOR*PEX*). The presentation of our findings has had a significant impact in shaping future directions in observing systems, synoptic and mesoscale research, and coordinated programs for advancing the predictability of atmospheric weather systems. The most important application of our work is its contribution to the improvement of operational weather forecasting.

TRANSITIONS

My collaboration with Rolf Langland (NRL/Monterey) continues to contribute to the accelerated planning for THOR*PEX*.

My work with Jim Doyle and William Thompson (NRL/Monterey) on the simulation and field validation of complex mesoscale flows will continue to be used to confirm the capabilities of the Navy mesoscale prediction system (COAMPS).

My collaboration with Xiaolei Zou (Fla.. State Univ.) will continue to advance the four-dimensional data assimilation of surface-based and reconnaissance aircraft *in situ* observations, and satellite active - and passive remote observing systems into global and regional prediction forecast models.

My new effort at using high-spatial resolution (~50 km) research aircraft dropsondes to calibrate/validate space-based observing systems will contribute to the more effective utilization of satellite observing systems in the monitoring and forecasting of weather systems.

PUBLICATIONS

Doyle, James D. and M. Shapiro,1999: Flow response to large-scale topography: the Greenland tip jet. *Tellus*, **51A**,729-748.

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Langland, R. H., R. Gelaro, G. D. Rohaly, M. A. Shapiro, 2000: Targeted Observations in FASTEX: Adjoint-Based Targeting Procedures and Data Impact Experiments in IOPs-17 and 18. *Quart. J. Roy. Meteor., Soc.*, 125, 3241-3270, 1999. Wernli, H., Shapiro, M. A. and Schmidli, J., 1999. Upstream development in idealized baroclinic wave experiments. *Tellus*, **51A**, 574-587.

Shapiro, Melvyn A., H. Wernli, N. Bond, and R. Langland, 2000: Effects of the 1997-1999 ENSO on extratropical baroclinic life cycles over the eastern North Pacific. *Quart. J. Roy. Meteor., Soc.* (Accepted for publication Sept. 2000)**.**

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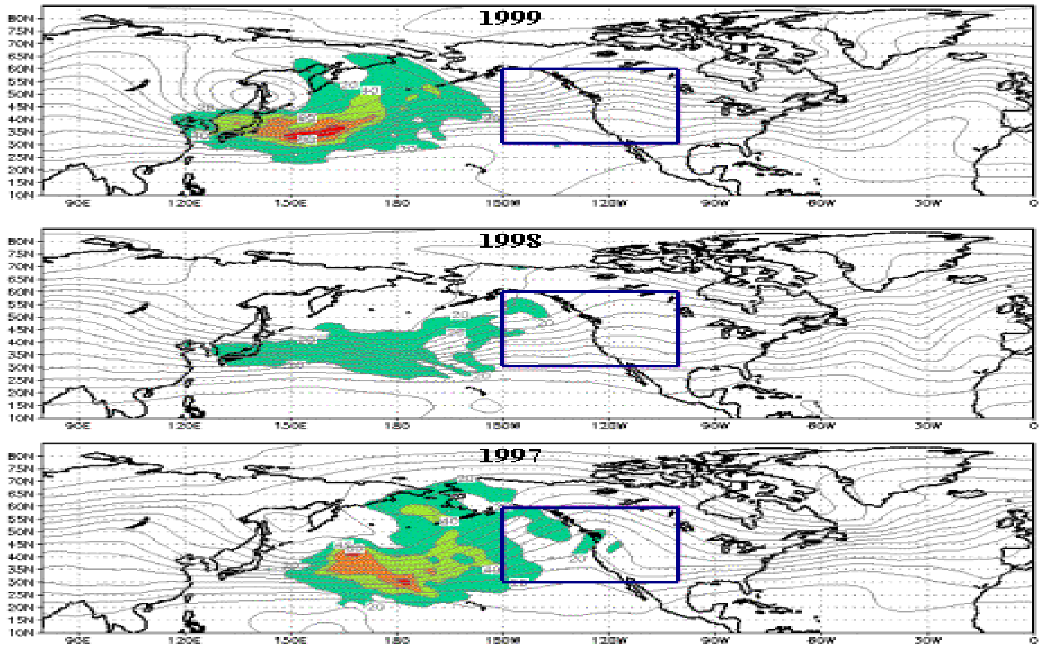

Figure 1: Initial condition sensitivity for 72-hour forecast cases with the largest errors during January and February. Forecast errors verify in the area 30N-60N, 100W-150W. Average sensitivity in the nine worst forecast cases is shown for each year. The sensitivity combines wind, temperature and pressure from the surface to 150mb, and is computed with the adjoint of the Navy global model (NOGAPS). Sensitivity units are J kg^{-1}. The average of analyzed 500mb height for the nine cases in each year is shown as solid light contours (interval=60m).

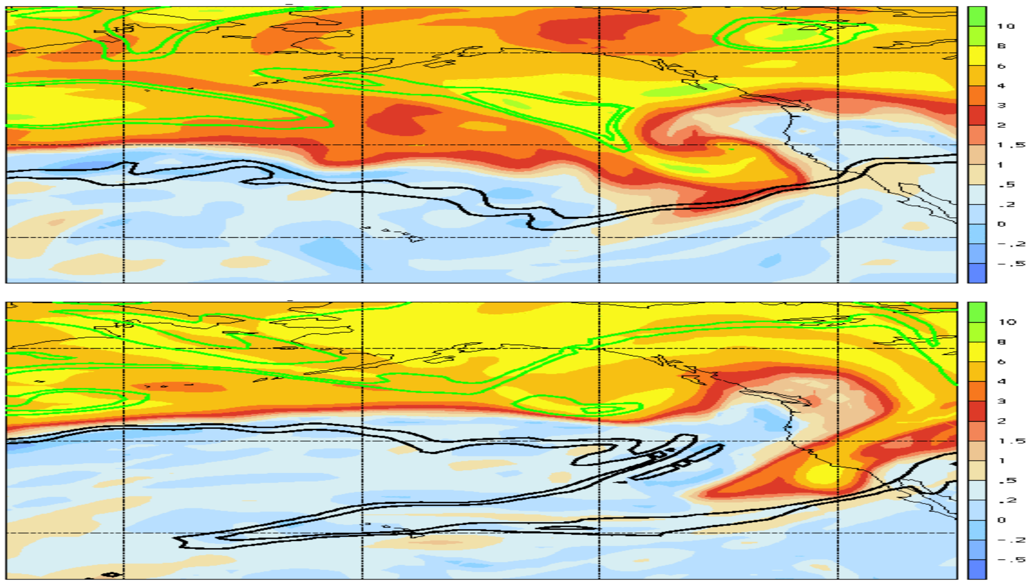

Figure 2: An example of the influence of ENSO time/mean flows on Rossby wave breaking at the tropopause. Potential vorticity (PV) at three isentropic levels (top) 1200 UTC 6 February 1998 (El Niño); (bottom) 1200 UTC 5 February (La Niña). 300-K PV (green lines, 2 and 3 PVUs); 320-K PV (color shading, as in color bar); 340-K PV (black lines, 2 and 3 PVUs) (ECMWF analyses).